Many different waveforms exist in electronic circuits. Some types of waveforms are referred to as TRANSIENT waveforms or voltages and exist in LR circuits. A TRANSIENT waveform, as previously studied, is one that changes from one steady state to another. The change usually repeats itself at regular intervals.

LR circuits as shown in FIGURE 2, consist of an inductor and a resistor. The circuit appears very simple in its structure but may contain transient voltages that have complex waveforms.

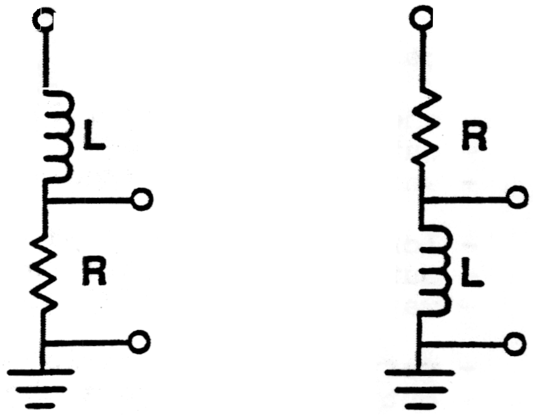


FIGURE 2

The resistor in an LR circuit opposes current and the inductor opposes a <u>change</u> in current.

Before calculating TIME CONSTANT/PULSE WIDTH ratios, it is necessary to understand what occurs in an LR circuit when transient voltages are applied. A transient input voltage can be simulated by use of a battery and switch as shown in FIGURE 3.

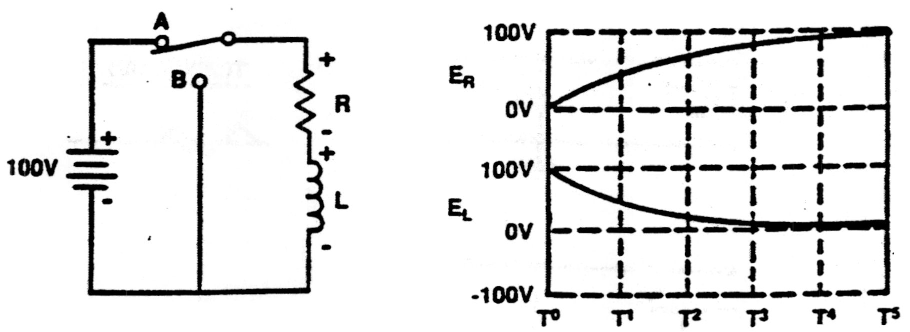


FIGURE 3

The graph shows the voltages across the resistor and inductor from time zero to time 5. In the LR circuit, inductor L is assumed to be perfect, that is, it offers only reactance and no resistance to DC.

When the switch is placed in position A, initial current from the battery starts to flow. Voltage across the resistor begins to increase and voltage across the inductor begins to decrease. This action is caused by the counter electromotive force (CEMF) of the coil.

At time T5, voltage across the inductor reaches zero and voltage across the resistor is equal to the applied voltage.

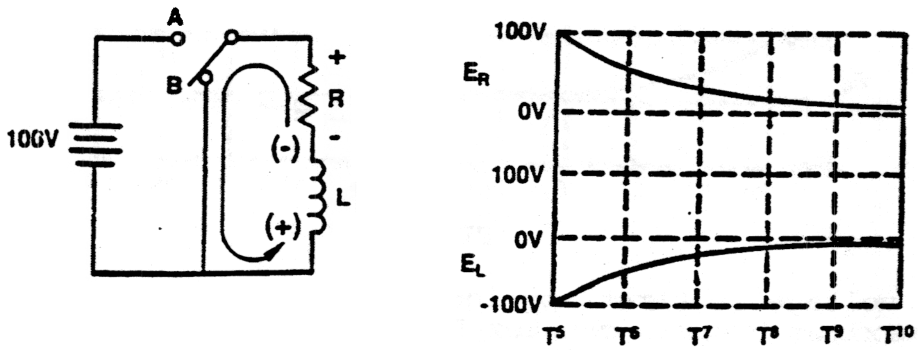


FIGURE 4

FIGURE 4 is the same LR circuit as shown in FIGURE 3, except the switch is in position B. When the switch is placed in this position the battery is removed from the circuit and the magnetic field around the coil collapses. Collapsing of the magnetic field induces a voltage in the coil as shown.

The graph shows voltages across the resistor and inductor, starting from T5, when the switch is placed in position B. Note that the voltage of the inductor starts at a high <u>negative</u> at T5 and reaches zero at T10. The resistor voltage begins at a high voltage at T5 and also reaches zero at T10.

During the time shown in this view the collapsing field of the inductor causes the inductor to provide the source voltage. The induced voltage is opposite to the original source but tends to keep current flowing in the same direction.

Figure 5 shows the combined actions explained in the two previous figures. It should be evident that CEMF of the coil plays a major role in formation of voltages across both the resistor and inductor.

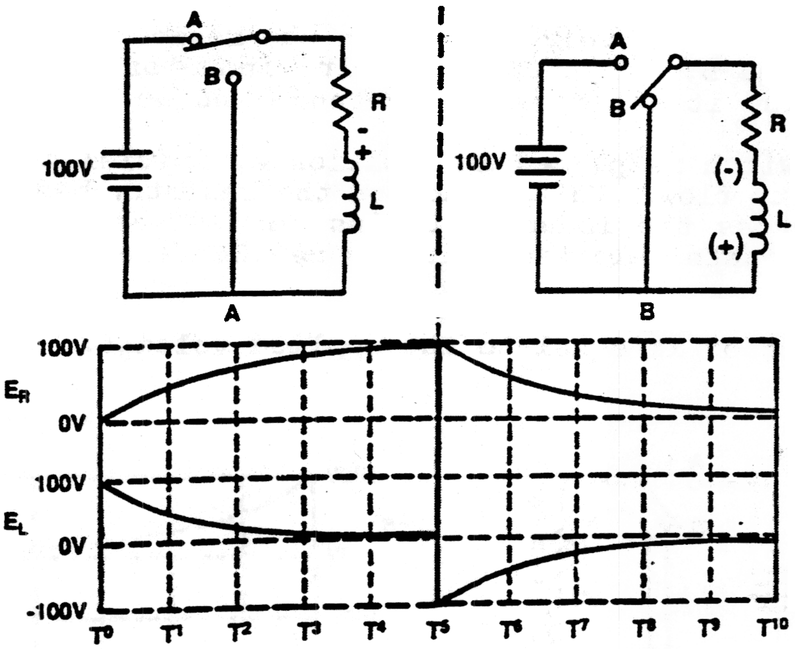


FIGURE 5

When voltage is first applied to the circuit at A, voltage of the coil is maximum because counter EMF is maximum. The resistor voltage is zero because the CEMF allows NO current to flow.

As time continues to T5, voltage of the resistor increases to the applied voltage and the inductor voltage decreases to zero.

From T5 to T10 the inductor voltage returns from a maximum negative to zero. The resistor voltage also returns to zero.

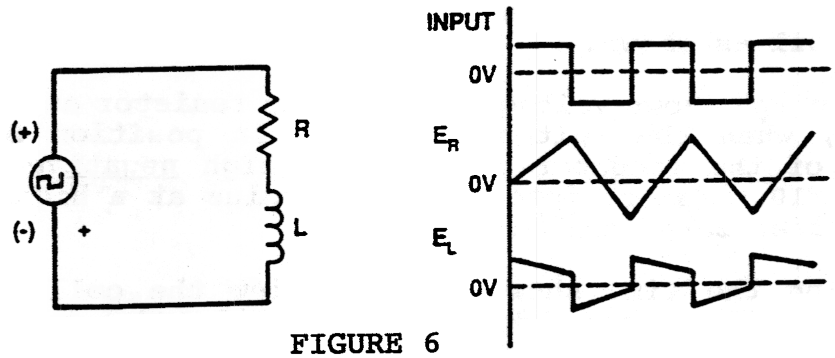


FIGURE 6

Figure 6 shows the same LR circuit as in previous figures, except the battery has been replaced with a square wave generator. One other difference is that the square wave input has both a positive and negative alternation, that is, it is an AC waveform. Current in this circuit will flow first in one direction and then in the opposite direction.

Resistor and inductor voltage waveforms shown in the graph are only examples for an LR circuit. Waveform shapes depend on circuit characteristics. For example, a definite amount of time is required for the induced voltages in the coil to build up and decay. In other words, a time constant exists in an LR circuit similar to an RC circuit.

TC = TIME FOR CURRENT TO REACH APPROXIMATELY 63% MAXIMUM CURRENT ON BUILD-UP. E_R IS DIRECTLY PROPORTIONAL TO CURRENT.

OR

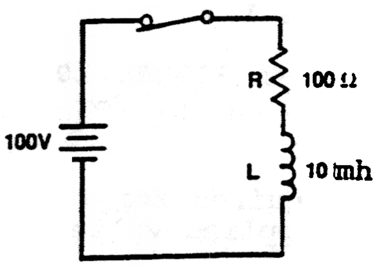
$$TC = \frac{L \text{ (in henries)}}{R \text{ (in ohms)}}$$

FIGURE 7

One time constant is that period of time required for the resistor voltage to reach approximately 63% of the applied voltage. It takes five time constants for the resistor voltage to reach approximately 99% of the applied voltage.

The RL time constant is also a ratio of the coil value in henries to the resistor value in ohms.

The formula $TC = \frac{L}{R}$ is a ratio expression of coil value in henries to resistor value in ohms. This formula $TC = \frac{L}{R}$ will be used in this lesson to determine the time constant of an LR circuit. This will give the TC in seconds. However, the practical unit is microseconds.



$TC = \frac{L}{R}$

$TC = \frac{.01 \text{ HENRIES}}{100 \text{ OHMS}}$

$= \frac{10^{-2}}{10^{2}}$

$= 10^{-2} \times 10^{-2}$

$= 10^{-4}$ SEC

TC = 100 MICROSECONDS

FIGURE 8

FIGURE 8 shows how to calculate the time constant of an LR circuit when the resistor and inductor values are known. Study the example used in this solution for determining the time constant and ensure that you understand the procedure.

One time constant is 100 microseconds. This means that in 100 microseconds the resistor voltage would be approximately 63% of the applied voltage or 63 volts. It would take five time constants or 500 microseconds for the resistor voltage to reach approximately 99% of the applied voltage.

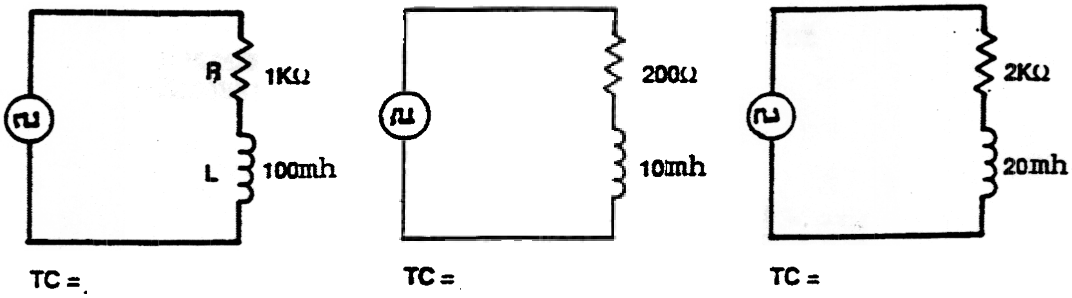


FIGURE 9

Calculate the time constant for each of the three LR circuits shown FIGURE 9. Use the formula $TC = \frac{L}{R}$. When L is in henries, and R is in ohms, then the TC will be in seconds. However, the practical unit is microseconds.

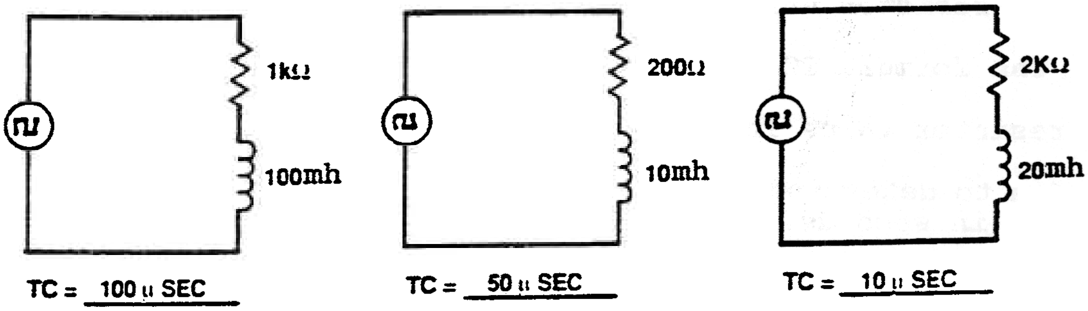


FIGURE 10

The correct answers are shown in FIGURE 10. If you are having difficulty determining the time constant for LR circuits ask the instructor for assistance.

How many time constants are required for the resistor voltage in an LR circuit to reach 99% of the applied voltage?

Five time constants are required. This would be true for any LR circuit.

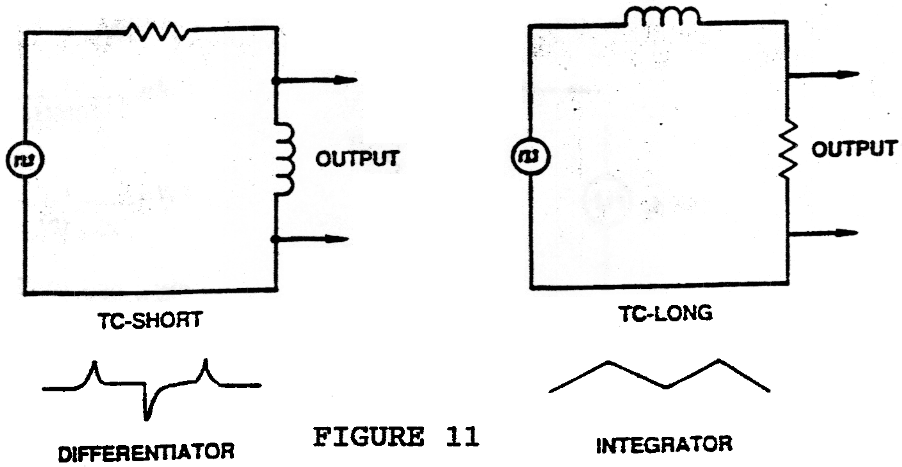
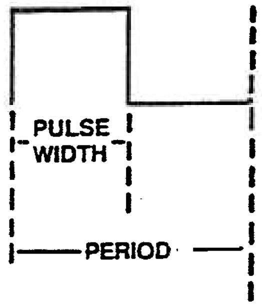


FIGURE 11

Time constants in LR circuits play an important part in the output waveshapes. The two circuits shown in FIGURE 11 are LR circuits having short and long time constants.

The first circuit has a <u>short</u> <u>time</u> <u>constant</u> and it's output is taken from across the coil. The output is a <u>spiked</u> or <u>differentiated</u> waveform. A circuit of this type is referred to as a <u>differentiator</u>.

The second circuit has a <u>long</u> <u>time</u> constant and it's output is taken from across the resistor. It produces the output shown and is referred to as an <u>integrator</u>.



$PW = \frac{P}{2}$ OR $P = 2(PW)$

$F = \frac{1}{P}$ OR $P = \frac{1}{F}$

$PW = \frac{1}{2F}$

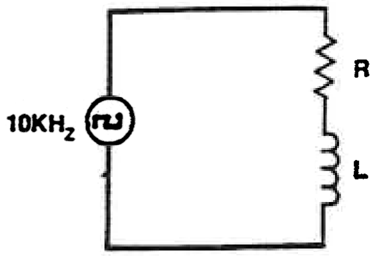
FIGURE 12

It was mentioned previously that the time constant of an LR circuit plays a part in determining the output waveshape. The pulse width of the input signal also plays a role in determining the output waveshape.

For example, a square wave is used as an input to an LR circuit. The pulse width, in this case, is equal to period divided by two or, period is equal to the pulse width multiplied by two.

You learned previously that frequency and period have a relationship expressed by the formula, frequency equals one divided by period or, period equals one divided by frequency.

If period is equal to one divided by frequency, then pulse width is equal to one divided by two times the frequency.



$$PW = \frac{1}{2F}$$

$$PW = \frac{1}{2 \times 10KH_Z}$$

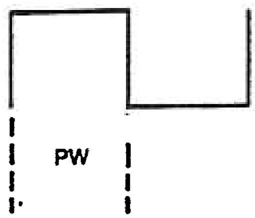
$$PW = \frac{1}{20 \times 10^3}$$

$$PW = .05 \times 10^{-3} \text{ SEC}$$

PW = 50 MICROSECONDS

FIGURE 13

FIGURE 13 shows a method for determining the pulse width of a square wave used as an input to an LR circuit. The formula $PW = \frac{1}{2F}$ used here will be used in calculating pulse width during this lesson.



$$PW = \frac{1}{2F}$$

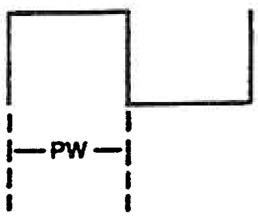
5 KH$_Z$ PW =

1 KH$_Z$ PW =

20 KH$_Z$ PW =

FIGURE 14

Calculate the pulse width for each of the frequencies given in FIGURE 14. Use the formula $PW = \frac{1}{2F}$



$$PW = \frac{1}{2F}$$

5 KH$_Z$ PW = <u>100 uSec</u>

1 KH$_Z$ PW = <u>500 uSec</u>

20 KH$_Z$ PW = <u>25 uSec</u>

FIGURE 15

The answers are shown in FIGURE 15.

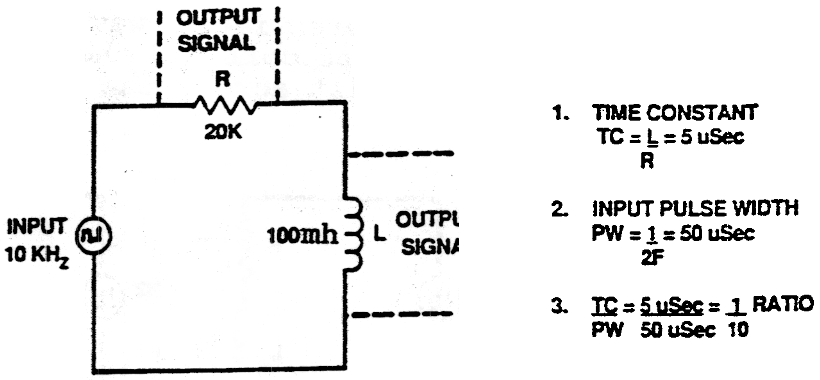


FIGURE 16

Figure 16 shows an LR circuit consisting of a 20K ohm resistor and a 100 millihenry coil. The time constant of this circuit is equal to 100 millihenries divided by 20K ohms or 5 microseconds.

The input pulse width of the square wave input to the circuit is equal to 20K hertz divided into one or 50 microseconds.

Output signals from this circuit across the resistor and across the coil would have waveshapes depending upon the time constant/pulse width ratio. The time constant/pulse width ratio is obtained by reducing 5 microseconds time constant over 50 microseconds pulse width to one-over-ten.

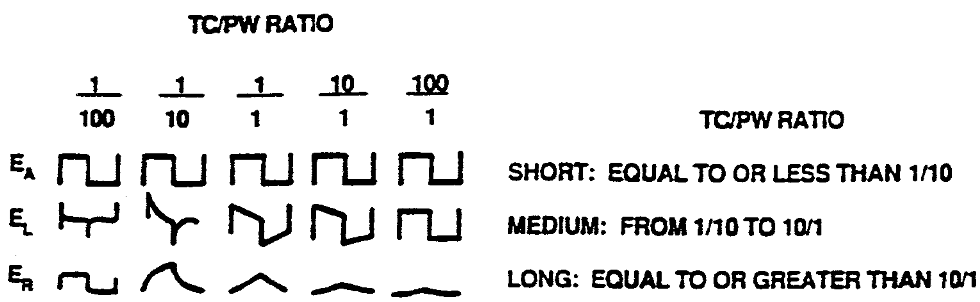


FIGURE 17

FIGURE 17 shows waveforms that exist in LR circuits having various time constant/pulse width ratios. For example, locate the one-to-ten time constant/pulse width ratio in the figure.

Below the one-to-ten ratio is a square wave which is the input to an LR circuit. What type of waveform would be found across the inductor or coil EL?

It would be a spiked or differentiated waveform. Notice the difference in this waveform across the coil and the waveform below it, which is the waveform that would exist across the resistor E_R.

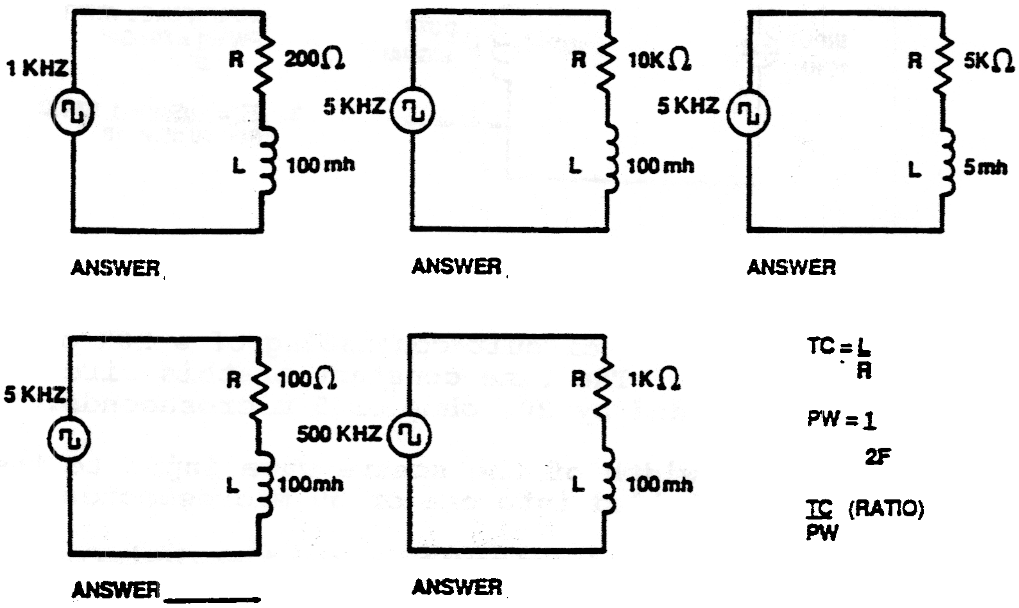
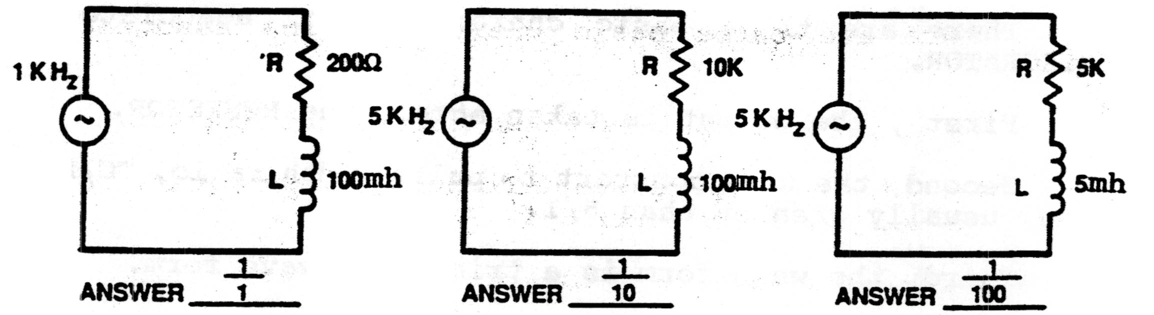
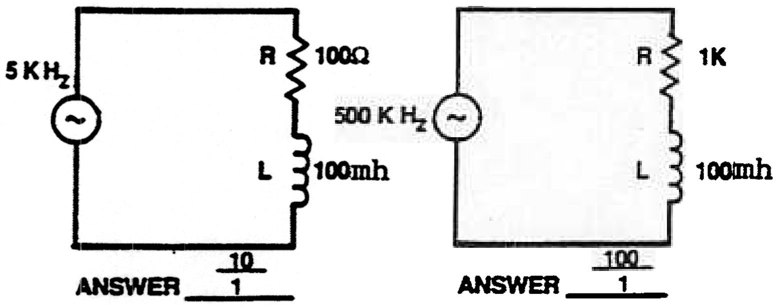


Figure 18

Calculate the Time Constant (TC)/Pulse Width (PW) ratios for each of the LR circuits in figure 18. The required formulas are shown. First calculate the <u>time constant</u>. Next, calculate the <u>pulse width</u>. Record the <u>TC/PW ratio</u> answer for each of the circuits. The answers for the calculated time constant and pulse width should be in microseconds.

The correct answers for the time constant/pulse width ratios are shown in figure 19. It is important to understand that time constant/pulse width ratios of LR circuits determine output waveforms.





$TC = \frac{L}{R}$

$PW = \frac{1}{2F}$

$\frac{TC}{PW}$ RATIO

FIGURE 19

There are three basic characteristics associated with the LR DIFFERENTIATOR.

First, the output is taken across the inductor.

Second, the time constant to pulse width ratio, TC/PW is less than 1/10.

Third the waveform is a spiked waveform. This is demonstrated in FIGURE 20.

$$TC = \frac{L}{R} = \frac{100 \times 10^{-3}}{20 \times 10^{3}} = 5 \text{ usec}$$

$$PW = \frac{1}{2f} = \frac{1}{2(10 \times 10^{3})} = 50 \text{ usec}$$

$$\frac{TC}{PW} = \frac{5}{50} = \frac{1}{10}, \text{ short TC}$$

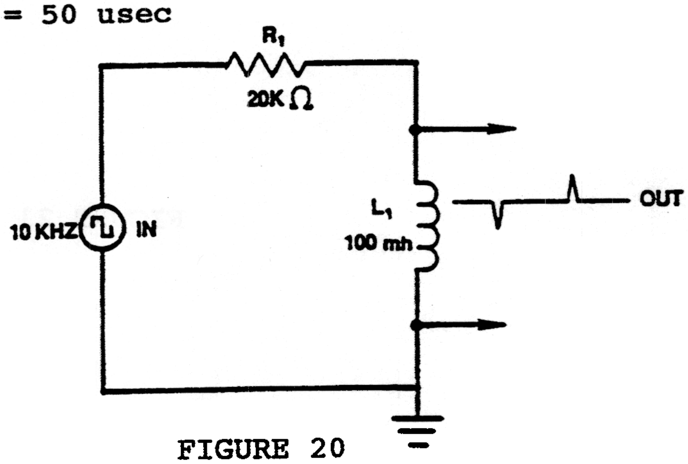


FIGURE 20

There are three basic characteristics associated with the LR INTEGRATOR.

First , the output is taken across the RESISTOR.

Second, the time constant to pulse width ratio, TC/PW is medium to usually greater than 5/1.

Third, the wave form is a triangular wave form.

This circuit is demonstrated in FIGURE 21.

$$\frac{L}{R}$$

$$\frac{100 \times 10^{-3}}{2 \times 10^{3}}$$

50 usec

$$PW = \frac{1}{2f}$$

$$= \frac{1}{2(100 \times 10^{3})}$$

= 5 usec

$$TC/TW \quad \frac{50}{5} = \frac{10}{1} \quad \text{Long TC}$$

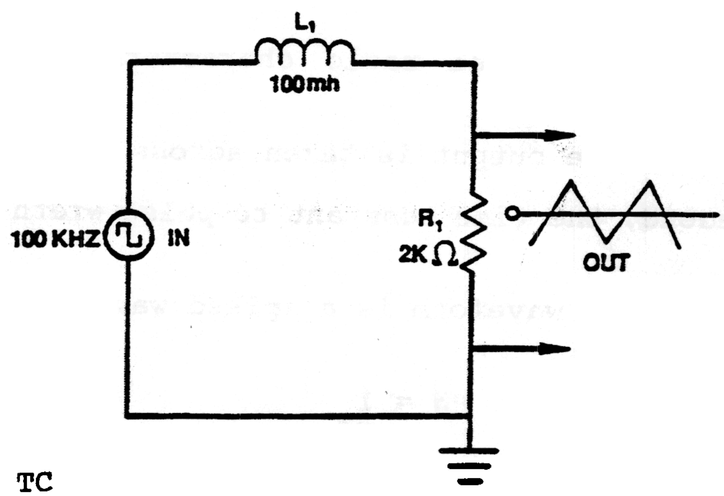


FIGURE 21

There are three basic characteristics associated with the LR COUPLER.

First, the output is taken across the inductor

Second, the time constant to pulse width ratio is long, 100/1 or greater.

Third, the waveform at the output is the same as the input

This circuit is demonstrated in FIGURE 22.

$$TC = \frac{L}{R}$$

$$\frac{100 \times 10^{-3}}{200} = .500 \times 10^{-3}$$

500 usec

$$PW = \frac{1}{2f}$$

$$\frac{1}{2\ (100 \times 10^{3})} = .005 \times 10^{-3}$$

5 usec

$$TC/PW = \frac{500}{5} = \frac{100}{1}, \text{ Long.}$$

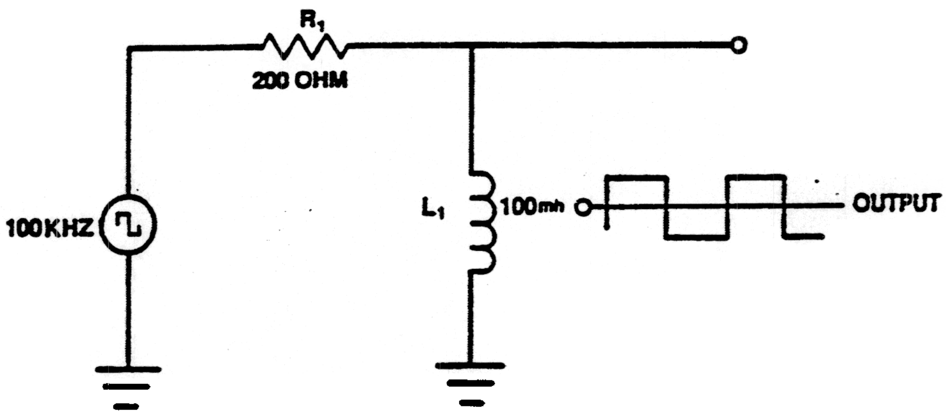


FIGURE 22

SUMMARY:

During this lesson you have studied transients in LR circuits. Because the inductor opposes any change in current, the current rises and falls in a manner similar to the voltage drop across the capacitor in an RC transient circuit. While the LR circuit is not used as often as the RC circuit, you will encounter LR circuits in guided missile electronics packages from time to time. For this reason you must know and understand the operation of transients in LR circuits.